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A monthly squadron sortie scheduling model for improved combat readiness

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A MONTHLY SQUADRON SORTIE SCHEDULING MODEL
FOR IMPROVED COMBAT READINESS

by

John D. Van Brabant

September 1993

Thesis Advisor: R. Kevin Wood

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An integer programming approach is taken to planning sorties for an operational squadron in the U.S. Navy. The model is designed as a decision aid for squadron operations officers in the planning of monthly flight schedules with the goal of maximizing squadron combat readiness by maximizing a weighted sum of readiness levels over all mission areas. Squadrons in each aviation community try to maximize readiness by flying training "events", subject to certain restrictions including: limited funding, limited availability of training facilities, a required number of aircraft per flight, flight time equity among pilots, and maintaining minimum levels of readiness in each mission area. An integer programming model, applicable to most squadron types, is implemented on a PC to maximize squadron readiness subject to those restrictions. The model is programmed in the GAMS language and solved in 5 minutes on 80486/33MHz computer with the XA solver. The output is a matrix of pilot-to-event assignments and shows the projected squadron readiness following the implementation of the proposed monthly schedule.

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A MONTHLY SQUADRON SORTIE SCHEDULING MODEL FOR IMPROVED COMBAT READINESS

by

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ABSTRACT

An integer programming approach is taken to planning sorties for an operational squadron in the U.S. Navy. The model is designed as a decision aid for squadron operations officers in the planning of monthly flight schedules with the goal of maximizing squadron combat readiness by maximizing a weighted sum of readiness levels over all mission areas. Squadrons in each aviation community try to maximize readiness by flying training "events", subject to certain restrictions including: limited funding, limited availability of training facilities, a required number of aircraft per flight, flight time equity among pilots, and maintaining minimum levels of readiness in each mission area. An integer programming model, applicable to most squadron types, is implemented on a PC to maximize squadron readiness subject to those restrictions. The model is programmed in the GAMS language and solved in 5 minutes on 80486/33MHz computer with the XA solver. The output is a matrix of pilot-to-event assignments and shows the projected squadron readiness following the implementation of the proposed monthly schedule.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

Training standards to maintain tactical proficiency in Naval aircraft are specified by Commander Naval Air Force U.S. Pacific Fleet/Commander Naval Air Force U.S. Atlantic Fleet Instruction 3500.67B/63B. This instruction defines a set of syllabi for each aviation community, which describe the training "events" (set of flights) which must be periodically repeated to cover training in applicable "Primary Mission Areas". The syllabi are matrices which list the points awarded to a pilot in each mission area upon completing a training event, the number of aircraft required for each event, and the time until the event must be repeated. Squadrons in each community are required to maintain minimum levels of readiness in each mission area at certain periods in their training, subject to certain restrictions: limited funding for fuel, limited availability of training facilities, a required number of aircraft per flight, and flight time equity among pilots. This thesis presents an integer program, implemented on a PC, that maximizes squadron readiness subject to those restrictions.

Squadron operations officers currently produce daily training flight schedules based upon cumbersome and time-consuming "best guess" calculations to try to maximize squadron readiness. The model presented in this thesis, designed to be a decision aid for squadron operations officers, produces a consistent and flyable set of pilot-to-event assignments to be scheduled over the period of one month, in order to

maximize squadron readiness. The model solves in only a few minutes on a PC and therefore gives the user the flexibility to produce "what if" scenarios based upon changing sortie levels and changing asset availability. The model user may also emphasize one mission area over another, in response to changing training goals, by modifying mission area "weights".

The model allows a squadron to maximize readiness in accordance with published requirements as set forth by Commander Naval Air Force U.S. Pacific Fleet and Commander U.S. Naval Air Force Atlantic Fleet.

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I. INTRODUCTION

Since the advent of the Naval Air Training and Operating Procedures Standardization (NATOPS) program in the late 1950s, every U.S. Navy combat squadron has been required to maintain professional competency by completing a series of designated training flights or "events" and by repeating these events at regular intervals. This regimen of events is specifically designed to cover the entire spectrum of primary and secondary mission requirements for each aviation community and ensures that squadrons maintain the high levels of readiness required of them by their respective fleet commanders. This thesis develops an integer programming model to help the squadron operation officer(s) maximize squadron readiness by efficiently scheduling pilots for training events subject to published training requirements, while not exceeding available funds for purchasing fuel.

A. READINESS

Readiness can be defined as the capability of a squadron to perform an assigned mission. Training is the means by which units achieve readiness. Currently, Naval Aviation Squadrons are required to report combat readiness status on a monthly basis to their respective fleet commanders. These fleet commanders, Commander Naval Air Forces Pacific (CNAP) and Commander Naval Air Forces Atlantic (CNAL) have jointly set forth comprehensive training, reporting, and readiness standards in an instruction that encompasses all segments of Naval Aviation. [Ref. 1] These segments, or "communities" are each responsible for maintaining proficiency in a number of fields called Primary Mission Areas (PMAs). There are currently 15 aviation communities to cover the 13 PMAs vital to U.S. Naval operations. APPENDIX A offers a brief description of each community by aircraft type and APPENDIX B lists each aviation community and the PMAs that apply to them.

U.S. Naval Aviation squadrons must operationally deploy at the highest level of readiness that can be achieved. A high level of readiness ensures the capability to effectively execute operational missions as directed by higher authority. This is achieved in part by completing a syllabus of flights or training events which carry with them specific training requirements [Ref. 1]. Hence, prior to any operational deployment, squadrons seek to maximize their combat readiness by completing syllabus training events as effectively as possible given the restrictions of time, money, and training asset availability.

Every squadron is given a quarterly allotment of funds for training which includes money for fuel. This allotment translates into a limit on the number of training sorties that may be flown. In the face of ever increasing fiscal austerity, squadrons must plan effectively to make optimal use of the minimal dollars allotted for peacetime training.

In addition to monetary ceilings, supplementary training assets are required to complete many training events. This creates additional obstacles to efficient scheduling. Bombing or torpedo ranges, electronic warfare services, aircraft carriers (including small decks for helicopters), and military operating areas are not always available on an as-needed basis. When an opportunity to make use of a training asset is presented, a squadron must be prepared to take full advantage of the services being offered or be faced with a less-than-combat ready status at a crucial point in training.

Once a training event is completed by a pilot, the pilot is considered "current" or up-to-date in the event for a specified number of months, and the pilot is awarded readiness points for each PMA that the training event addresses. A pilot may earn up to 100 points in each mission area and the number of points a pilot has in each PMA is positively correlated to that pilot's readiness. Squadron readiness in each mission area is then based upon the average readiness level (points) of its pilots in a given mission area. Prior to the lapse of currency in an event the pilot must again complete the event to maintain currency. Failure to do so results in the loss of readiness points for that event. Allowance for published training restrictions [REF. 1] and the demand for the update of readiness status in each event make squadron planning essential for efficient day-in and day-out operation.

This thesis is primarily concerned with the operations of those squadrons that deploy as a single unit onboard aircraft carriers, as part of an operational airwing, which consists of squadrons from various aviation communities. However, the majority of the modeling is applicable to other communities as well.

Operational deployment schedules for combat squadrons usually cover an extended period of time and involve three distinct phases. These phases are *Post-Cruise Standdown, Workups, and Deployment* and will be discussed in the next section.

B. SQUADRON TRAINING AND READINESS

There are 3 different phases or periods of training that each naval squadron must go through during its existence within the Navy. *Post-Cruise Standdown, Workups,* and *Deployment* comprise the deployment cycle which lasts between 1½ to 2 years. Understanding the phases of the deployment cycle and the training requirements of each is essential to understanding the tempo of operations and readiness standards expected during each phase.

1. Post-Cruise Standdown

Following operational deployment, a squadron will normally enter a phase of training and readiness referred to as *Post-Cruise Standdown.* While in this phase the squadron is not expected to be in a combat-ready condition. Often during this phase, currency has lapsed in a majority of the training events due to the rotation and replacement of pilots and the leave and liberty policies of the squadron. It is during this time that squadrons routinely fly only those flights that are necessary to maintain an aviator's basic skills including radio instrument navigation, emergency procedure training, and landing pattern skills. Training in specific warfare skills such as bombing. air-to-air combat, and anti-submarine warfare are, to a certain extent, neglected during Post-Cruise Standdown which may last 1½ to 3 months. Scheduling during the Post-Cruise Standdown is not difficult due to the squadron's low tempo of operations.

2. Workups

Workups are that portion of the deployment cycle where the squadron retrains pilots in preparation for operational deployment. In this phase the squadron will quite often start from a near zero-points base and begin to accumulate readiness points. The squadron strives, by the end of this phase, to have an average of 75 points for each pilot in each PMA, which is the minimum number of points needed to be considered combat ready. Workups are marked by an increased tempo of ashore operations combined with numerous fleet exercises, which include large numbers of surface combatants and any aircraft assigned to them. Although fiscal allocations during this time frame are at normal operational levels, they are historically below levels desired by squadron commanding officers. Plainly, the commanding officers must make efficient use of all resources to insure, if nothing else, that the combat-ready standard will be reached in all PMAs.

The Workup period is normally 12 to 15 months. As the squadron approaches the end of this phase of training, the training schedule of the squadron is heavily influenced by the requirement for the squadron to conduct integrated training exercises with the aircraft carrier it is assigned to. During this period it is the aircraft carrier's deployment schedule which dictates the operating tempo. At various times, because of national policy decisions, Workups may be shortened to as little as 8 months. Shortening this phase has the obvious effect of increasing the operating tempo of the squadron and places a premium on timely completion of training events. Workups are by far the most important phase of the deployment cycle in terms of efficient scheduling of sorties. Poor scheduling practices can result in submission of readiness reports that reflect a less than adequate level of readiness and worse, may lead to unsafe habits in the pursuit of increased readiness.

3. Deployment

Deployment of a squadron is the final phase of the deployment cycle. During this phase most aviators have already achieved a combat-ready status and maintenance of qualifications is done by daily flight operations and recurrent exercises with other U.S forces or with allied forces. Since monetary allocations for fuel are usually larger during deployment, maintaining currency in training events becomes somewhat easier. This, however, does not imply that any additional funding beyond what is initially allocated will be easier to obtain. Therefore, the squadron commander must be as aware of training needs and limits on sorties during deployment as he is during workups.

Demands on scheduling will vary depending upon the phase of the deployment cycle the squadron is in. Of the three phases described, *Workups*, by far, places the greatest emphasis on efficient daily operations and proper planning.

C. SORTIE SCHEDULING TO MAINTAIN PROFICIENCY

Squadrons are budgeted monies quarterly, designated to cover the cost of operating aircraft over the three month period. Subsequently, each squadron is responsible for the expenditure of these funds on fuel in a manner that most effectively meets all scheduled and unscheduled obligations during the quarter while not exceeding the allotment. Quite often, a squadron will deplete these funds, close to, but, prior to the end of the quarter, and either request supplementary funding or not fly for those few remaining days. On the other hand, a consideration frequently overlooked in squadron planning is the issue of under-utilization of allocated funding. Failing to expend funds which are budgeted without well-documented reasoning often results in reduced future funding for flight operations. This section discusses current scheduling methods and how this thesis plans to improve the techniques used in an effort to promote efficient scheduling of training events.

1. Traditional Scheduling Methods

Currently, squadrons rely almost exclusively on trial-and-error methods and hand calculations for monthly planning and beyond. Operations officers often face unforeseen problems such as severe weather, aircraft breaking down, and pilot illness which cause cancellation of events. The cumbersome task of manually recalculating current readiness and projected readiness levels for each squadron pilot and manually altering monthly schedules is inefficient and is unlikely to truly maximize readiness subject to limited funds. By using a computerized scheduling aid, squadron operations officers may be able to dramatically reduce the time required to schedule pilots for training events, and appreciably improve the level of squadron readiness.

2. Attacking the Problem

This thesis develops a mixed integer programming model as a scheduling aid for squadron operations officers. The model is implemented in GAMS [Ref. 2] and is solved using XA version 8.0 [Ref. 3]. It is designed to assign pilots in a squadron to training events, during the course of a month, while maximizing the readiness of the squadrons in accordance with published policy and procedures [Ref. 1]. The thesis model is based on preliminary work completed by CDR Steven Walker [Ref. 4]. His model solved on an AMDAHL Model 5995 mainframe computer in approximately 5 minutes, for only 5 pilots. Squadrons typically have between 15 and 24 pilots assigned and therefore, use of the original model is limited. Reformulation of the model allows it to be solved for an operational squadron on a 486DX/33MHz personal computer. It has been made as generic as possible to be of significant use to most aviation communities with only minor modifications to the input data.

The model is designed to be an aid for squadron operations officers, but not replace their decision making. The output of the program is a matrix of pilots and training events indicating which pilots to assign to what events during the training period, a matrix of pilot readiness levels and point levels in specific mission areas that will be achieved if those events are scheduled and carried out, and the squadron readiness levels in those same mission areas. The operations officer must then produce the day-to-day schedule over the time horizon chosen, from the pilot/event output matrix, and make modifications resulting from last minute changes or unmodelable details.

D. RELATED MODELS

1. Walker's Model

Walker [Ref 4] developed an integer programming model for scheduling aviators assigned to an F-14 squadron which is the basis for the model in this thesis. His model schedules aviators for events based upon pilots' current readiness levels, events currently completed, and a maximum number of sorties allowed for the training period. Walker's model assigns individual pilots to 1 of 4 levels of readiness based upon the total number of readiness points that would be earned. Individual levels of pilot readiness are then transformed to reflect the readiness level of the squadron.

Walker's model addresses sorties available for the training period as well as flight time equity among pilots, in an effort to maximize the overall readiness of an F-14 squadron via individual pilot readiness. The model as originally formulated was too complex to be solved on a PC and was tested on an AMDAHL mainframe computer. Since a major goal of this thesis was to solve this problem on a PC, a reformulation is necessary.

2. Training Squadron Scheduling

Kawakami [Ref. 5] presents three models for the training of helicopter pilots in both the Japanese Defense Force and the U.S. Marine Corps. Helicopters (as well as other multi-crewed aircraft) present a unique problem concerning scheduling. Helicopters require 2 pilots for each training event thereby giving the scheduler up to $\binom{N}{2}$ ways to schedule N pilots. Kawakami separates aircraft commanders from co-pilots and creates the first two models, one for scheduling aircraft commanders and the other for scheduling co-pilots. He also separates daytime and nighttime into distinct scheduling periods creating a daytime and nighttime variant for each model. His objective is to maintain an individual pilot's level of currency by scheduling specific maneuvers peculiar to Japanese Defense Force helicopter squadrons. These scheduled maneuvers are then combined manually to form separate events. The similarities between Kawakami's model and the modeling concerns presented in this thesis are the constraint placed on the number of sorties that may be scheduled, the expiration of qualifications, a limit on the flight hours per pilot, and the training of those pilots at a lower level of readiness. Kawakami chooses to place a hard limit on the number of maneuvers that may be performed by each pilot in a day rather than allow the model to choose "opportune moments" to violate the limit for the sake of increased readiness. Another modeling concern of this thesis is the flight time equity among pilots which is not addressed by Kawakami.

Kawakami's third model addresses the idiosyncratic nature of a U.S. Marine Corps training squadron. Training squadrons have the unique mission of instructing aviators to fly a specific aircraft type at a designed level of proficiency. In these cases, a stepwise training syllabus is utilized to ensure that fledgling aviators have mastered certain required skills prior to advancing through the syllabus and then on to their operational squadrons. Training events in fleet operational squadrons, with the exception of initial standardization flights, are not required to be completed in a specific sequence and therefore a model of this type is inappropriate.

3. Airline Crew Scheduling

Some scheduling problems have been solved using a model which employs set partitioning or generalizations. The set partioning model ensures that a set of tasks or requirements are filled using an appropriate work force. Scheduling in the airline industry has been accomplished in this manner for many years [Ref. 6]. Airline companies are concerned with satisfying the needs of the markets they serve. Logically, they must plan over some specified time horizon (a week or month usually) based upon projected trends of patronage. Flights are first scheduled to meet patron demands and the flights in turn creates demands for crews.

Since crews are home-based at certain airports, a series of flights must be scheduled for the crews to meet the demands for crews while minimizing cost to the airline. Airline cost minimization is subject to such constraints as: each route must be covered once with an appropriate crew, all FAA and union obligations must be met, crew rest must be allowed, time must be allotted for crew briefing and de-briefing, and days spent away from home base must be limited.

The set partitioning methodology first generates a set of potential schedules for each crew called *pairings*, which is a collection of flight requirements (routes) or *legs* which are covered by a designated crew. This set of candidate pairings is then combined in an integer program which selects the best combination of pairings, one for each crew, to meet demands for crews.

Operational squadrons have a less rigid scheduling problem because sequences of flights do not have to be established. Specifically, "demands" for flights are requirements for a pilot to fly an event from home base and back before a qualification is lost, and the order in which these events take place is immaterial. The set partioning approach might be useful, however, in establishing detailed day-to-day schedules for pilots which include dates for range availabilities and dates unavailable for flying because of collateral duties.

E. THESIS OUTLINE

A mixed integer programming approach is taken to solve the problem of monthly sortie planning. The model is only concerned with the scheduling of flights for officers assigned to fleet squadrons and assumes that all prerequisites to scheduling training events, such as ground training, are complete. The scheduling of enlisted crewmen that may be required is left for future research.

Chapter II presents background on flight scheduling. This describes criteria used for modeling and the restrictions they place on scheduling. Chapter III gives the mathematical formulation of the model. Chapter IV describes the testing of the model and includes germane variations of input data and results, and Chapter V tenders conclusions and recommendations. The GAMS formulation and input data are presented in the Appendices.

II. FLIGHT SCHEDULING BACKGROUND

The nature of the naval mission requires that maritime forces be capable of coping under diverse and unusual circumstances. Consequently, the U.S. Navy has many different types of squadrons that perform various missions. These squadrons operate fixed-wing propeller-driven, rotary-wing, and tactical jet aircraft that deploy onboard aircraft carriers, small surface combatants, and at overseas forward bases. Each squadron type offers a different scheduling scenario for its pilots, which for the greater part is dependent upon the number of aircrew onboard during each training event. When a small number of aviators is required per aircraft, certain assumptions can be made concerning training effectiveness and scheduling. However, when dealing with a large number of aviators per aircraft per event, such as in a maritime patrol squadron, those same assumptions are invalid. Therefore, it is important to discuss general squadron makeup to determine the most relevant scheduling approach. Although this thesis is primarily concerned with squadrons which deploy as a single unit onboard aircraft carriers, a description of other types of squadrons is included as the scheduling methods discussed may be appropriate for them as well.

A. GENERAL SQUADRON MAKEUP

The Navy maintains a wide variety of fixed-wing and rotary-wing aircraft in its inventory, each demanding different operating practices and manning levels. This section addresses those differences and categorizes squadrons in an effort to make reasonable assumptions for modeling purposes.

1. Fixed Wing Squadrons

a. Tactical Squadrons

The U.S. Navy operates tactical jet aircraft from the decks of conventional and nuclear powered aircraft carriers. The tactical airwings onboard consist of attack and fighter aircraft complimented by long range Anti-Submarine Warfare (ASW) aircraft (the S-3B), Command and Control aircraft (the E-2C), Electronic Warfare (the EA-6B) aircraft, and ASW helicopters (the SH-3H). For the purposes of this thesis, due to similar crew requirements, the S-3B and EA-6B squadrons are considered to be tactical squadrons, while the E-2C squadrons are considered to be maritime patrol squadrons.

Fighter and attack squadrons normally consist of a minimum of 13 and a maximum of 28 flight officers. Currently, the U.S. Navy operates only one single piloted or "single seated" aircraft, the F-18 Hornet. In those squadrons operating aircraft that require a pilot and a bombardier or navigator the number of pilots is approximately half the total number of flight officers. For the purposes of modeling, these crews of 2 to 4 officers are considered as one pilot. This assumption is based on the practice of maintaining "crew continuity during training". Specifically, during workups and for long periods of time during a deployment (one-fourth to one-half the deployment) an aircrew will fly most of its training missions as a cohesive group. By training in this manner, aircrews are more effective at their assigned mission as they are better able to predict the actions and responses of the other crew member(s). Another advantage to training extensively as a crew is that junior officers can be consistently assigned to crew with more senior and consequently more experienced officers from whom they learn the peculiarities of the aircraft and how to best utilize them during a mission. Scheduling for tactical squadrons may therefore be done using the assumption of crew continuity during training, i.e., a single "pilot", representing one crew, is scheduled for each flight.

b. Support Squadron

A support squadron, for the purposes of this thesis, operates the C-2, carrier onboard delivery (COD) aircraft. There are support squadrons currently operating in the Naval Reserve whose mission is to transport personnel and cargo to worldwide locations but their training requirements are not addressed in [Ref. 1] and shall not be considered. The COD does long range deliveries to organized battlegroups from supply points located in strategic positions. The squadron is normally composed of 20 to 30 pilots and a number of enlisted crewmen. The squadron deploys as detachments composed of enough crews to operate 2 to 3 aircraft. These aircraft operate with 2 pilots per crew and crew continuity during training may be applied here as well.

c. *Maritime Patrol*

The P-3C is the Navy's primary maritime patrol aircraft. Operating from land bases, P-3C squadrons have roughly 75 officers. Because the crew consists of up to 14 personnel in a mix of pilots, tacticians, and enlisted sensor operators, scheduling using the crew continuity assumption is not appropriate.

The E-2C is a carrier based Electronic surveillance and is the Navy's primary airborne command and control platform. The squadrons are comprised of 32 to 38 officers in a mix of pilots and tactical officers. Each E-2C crew consists of 5 officers and is too large to assume that continuity during training is still maintained.

Since a maritime patrol squadron consists of large numbers of the various crew members and crew continuity will not typically hold, the scheduling approach of this thesis is not applicable to this type of squadron.

2. Rotary Wing Squadrons

Every helicopter in the U.S. Navy is dual piloted with at least one enlisted crewman onboard for each flight. Each helicopter squadron maintains between 20 and 50 pilots depending on the community. Currently, only the SH-3H squadrons are deployed as a single unit onboard aircraft carriers. All other helicopter squadrons deploy individual detachments onboard aviation-capable surface combatants consisting of 1 to 5 aircraft with 4 to 12 pilots. Crew continuity during training is maintained by deployed squadrons and by detachments, as a detachment essentially operates as a small squadron when deployed.

Because the Navy operates such a diverse variety of aircraft, their training syllabus requirements are also diverse. The next section discusses specific requirements and how they may be addressed when scheduling training events.

B. SYLLABUS REQUIREMENTS

The syllabus requirements for training [Ref. 1] are straightforward, yet present some difficulty when scheduling pilots when there are limited resources available during the training period. These restrictions, which will be reflected in the constraints of the model are: the limited availability of special instrumented ranges (e.g., bombing, torpedo, and electronic warfare ranges), limited assets for shipboard landings ("decks"), the number of aircraft required for each training event, and the number of flights required for completion of each training event. These issues will be described in detail below.

1. Range Time and Deck Landings

The use of instrumented range facilities and the completion of shipboard landings are vital to almost all of the warfare communities in order to achieve combat readiness. There are two factors that influence the use of a range facility by a squadron, (1) when it is available and (2) the availability of funds (other than funds for fuel) to pay for operations at the range. Underway times for ships conducting landing qualifications are predetermined and decks only available to the squadron during prearranged periods.

a. The Range

Arranging for use of a range often requires contact with the agency controlling the range at least one month in advance. This allows the range operators to properly prepare the range for the specific events that need to be completed by the squadron. Since these ranges are normally distant from the squadron making use of the range (for example, the underwater acoustics and torpedo range at Andros Island, Bahamas is a five hour flight from the ASW helicopter squadrons in Jacksonville, Florida), the squadron will typically make use of the range on consecutive days. Trying to arrange for 3 to 4 consecutive days of use at these ranges on short notice is extremely difficult.

The funding required to pay for operations at these ranges is not available to the squadron on an as-needed basis. Therefore, events that require ranges subject to both range availability and limited funding. For the purposes of this thesis, unavailable funding for range time will be treated as a range unavailability.

b. Ship Availability

Fleet commanders regularly schedule aviation-capable ships for hosting ship landing qualifications. When considering landing qualifications for carrier-based aircraft, a squadron, as part of an airwing, will participate in this event once or twice during a six month period (obviously precluding extended underway periods during workups). For squadrons that base aircraft onboard small ships, the schedule is much the same. The effect on the squadron is that those events that involve shipboard landings cannot always be included as candidate events.

Modeling asset availability will be addressed by allowing events to be scheduled only if any special facilities those event require are available, and disallowing events that require unavailable assets.

2. Number of Aircraft Per Event

Many of the training events done by the tactical jet squadrons are done as multi-aircraft events, because of tactical doctrine. The majority of these events must be done as either a section, which is exactly two aircraft, or as a division, which is exactly four aircraft. This implies that one extra pilot or crew cannot be allowed to "tag along" on such events even if it would mean a significant gain in readiness points for the squadron. If an event is scheduled n times then the number of aircraft participating in the event must be $2n$ if the event requires a section and $4n$ for an event that requires a division. There are events that do not require exactly $k=2$ or $k=4$ aircraft however, and for these events a value k can be specified which is a lower bound on the number of aircraft which must participate.

Multi-aircraft events should only be scheduled when there are the requisite number of crews that are candidates to be scheduled for these events. In those cases where a single unqualified crews may need to fly a multi-aircraft event, qualified (and not about to lose qualification) crews may be scheduled for an event so that the single crew needing to complete the event may be accommodated.

3. Number of Flights Per Event

Each training event listed has associated with it a number of flights that must be flown for the event to be complete. This number is determined by the authors of the training instruction [Ref. 1] and is based on prior experience. This does not preclude the pilot(s) flying the event from completing it in less than the prescribed number of flights, if all event criteria are met. Because there is a limit on the number of sorties available, a prospective model should include a way to analyze the gain if the nominal limit on sorties is exceeded, which might be executed by flying the same events with fewer sorties. The squadron commander would have the option of staying within the limit or requesting additional funding for supplementary flights.

4. Expiration Dates

A pilot who has completed an event will have a date of expiration associated with that event which will dictate when the event must be completed again. Thus, a model should avoid scheduling those pilots who will not lose qualification in an event during the training period in question. In the case where a qualified crew must be scheduled to accommodate one that is unqualified, selection should be based on shortest time until expiration as well as readiness level benefit to the squadron.

C. FLIGHT TIME EQUITY

Flight time equity among pilots is an important concept when considering the operations of a combat squadron, and is important for two reasons. First, there is the aspect of maintaining basic airborne skills in the cockpit which will degrade when a pilot does not fly for an extended period of time. Second is the more subjective argument of decreased morale of those pilots who have not flown for long periods. Despite the importance of collateral duties a pilot may be responsible for within the squadron (e.g., maintenance officer or operations officer), an aviator's primary duty at a squadron is as a combat-ready pilot. Though airborne skills are a more important concern when producing operational flight schedules the notion of morale among pilots should not be discounted during the scheduling process. Operations officers normally address this issue on an *ad hoc* basis relying on individuals reporting scheduling discrepancies resulting in a lack of flight time.

To model the above concern, a level of equity must be imposed to ensure that no pilot will fly too many or too few training events. The level of equity will be an allowed deviation above and below the mean number of sorties per pilot during the training period.

III. MATHEMATICAL MODEL

The Monthly Sortie Planning Model will determine the optimal assignment of pilots to events and is designed to be used as a scheduling aid for squadron operations officers. The objective of the model is to maximize overall squadron readiness subject to flight time equity concerns among pilots, a specified number of aircraft per event, and the quarterly fiscal allocation for fuel. The problem is formulated as a modified assignment model where pilots are scheduled for events over a time horizon of one month.

A. INDEX SETS

$a \in A$	Mission area
$p \in P$	Pilot
$P_e \subseteq P$	Subset of pilots who are candidates to be scheduled for an event
$e \in E$	Training event
$E_p \subseteq E$	Subset of events that pilot p may fly during the training period
$E' \subseteq E$	Subset of training events where an exact number of pilots is required to complete the event
$E' \subseteq E$	Subset of training events where a minimum number of pilots is required to complete the event
$E'' \subseteq E$	Subset of events that can be scheduled during the training period

B. COEFFICIENTS AND PARAMETERS

1. Objective Function

W_a Weight assigned to each mission area reflecting the importance of the mission area to the squadron

H^f Penalty assessed for each sortie which exceeds the upper bound on sorties per pilot

L^f Penalty assessed for each sortie which falls below the lower bound on the number of sorties per pilot

U^{fu} Penalty assessed for each sortie scheduled beyond those allocated for the training period

U^{fl} Penalty assessed for each sortie below those allocated for the training period

2. Sortie Data

S_{pe} Number of sorties pilot p is required to perform for event e

S^{ub} Upper bound on the number of squadron sorties during a training period

S_p^U Upper limit on the number of sorties for pilot p

S_p^L Lower limit on the number of sorties for pilot p

G_e The minimum number of pilots required to complete event e

3. Points Data

T_{ea} Training points awarded upon completion of event e in mission area a

T_{pa}^a Additional points required for pilot p to achieve qualification in mission area a

4. Readiness Data

R^l Lower bound on pilot readiness

Q^l Lower bound on squadron readiness

C. VARIABLES

s_{pe} 1 if pilot p is scheduled for event e
0 otherwise

q_{pa} percentage of maximum additional points pilot p accumulates in mission area a

r_a percentage of maximum additional readiness points for squadron in mission area a

y_e 1 if event $e \in E'$ is scheduled
0 otherwise

x_e number of times event $e \in E'$ is scheduled

v_p^+ violation in sorties of the maximum number of sorties pilot p may fly during proposed training period

v_p^- violation in sorties of the minimum number of sorties pilot p must fly during proposed training period

f_p slack variable for the number of sorties flown by pilot p

t_{pa} number of additional points pilot p earns in mission area a

u^+ violation in sorties beyond the maximum number of squadron sorties allowed

u^- violation in sorties below the maximum number of squadron sorties allowed

D. FORMULATION

OBJECTIVE FUNCTION:

$$Maximize \sum_{a} W_a r_a - \sum_{p} H^f v_p^+ - \sum_{p} L^f v_p^- - U^{fu} u^+ - U^{fl} u^-$$

SUBJECT TO:

$$\sum_{e \in E'''} \sum_{p \in P_e} S_{pe} s_{pe} - u^+ + u^- \leq S^{ub} \qquad (1)$$

$$\sum_{e \in E_p} T_{ea} s_{pe} \geq t_{pa} \qquad \forall p \in P,\ a \in A \qquad (2)$$

$$t_{pa} - T_p^a q_{pa} \geq 0 \qquad \forall p \in P,\ a \in A \qquad (3)$$

$$\sum_{p} q_{pa} - |P| r_a = 0 \qquad \forall a \in A \qquad (4)$$

$$\sum_{p \in P_e} s_{pe} - G_e x_e = 0 \qquad \forall e \in E' \cap E''' \qquad (5)$$

$$\sum_{p \in P_e} s_{pe} - G_e y_e \geq 0 \qquad \forall e \in E'' \cap E''' \qquad (6)$$

$$x_e - s_{pe} \geq 0 \qquad \forall e \in E' \cap E''' \,,\; p \in P_e \tag{7}$$

$$y_e - s_{pe} \geq 0 \qquad \forall e \in E'' \cap E''' \,,\; p \in P_e \tag{8}$$

$$\sum_{e \in E_p} S_{pe} s_{pe} + f_p + v_p^- - v_p^+ = S_p^L \qquad \forall p \in P \tag{9}$$

$$R^l \leq r_a \leq 1 \qquad \forall a \in A \tag{10}$$

$$Q^l \leq q_{pa} \leq 1 \qquad \forall p \in P \,,\; \forall a \in A \tag{11}$$

$$S_p^u - S_p^L \geq f_p \geq 0 \qquad \forall p \in P \tag{12}$$

$$s_{pe} \in \{0,1\} \qquad \forall p, e$$

$$y_e \in \{0,1\} \qquad \forall e$$

$$x_e \in \mathbb{I}_+^e$$

$$\{v^+, v^-\} \in \mathbb{I}_+^p$$

$$\{u^+, u^-\} \in \mathbb{I}_+$$

$$0 \leq t_{pa} \leq 100 \qquad \forall p, a$$

E. DISCUSSION

1. Objective Function

The objective function is a simple linear function which seeks to maximize the sum of the weighted readiness values over the specified mission areas. The weights, which can be adjusted by the user, reflect the emphasis that the decision maker places on specific mission areas during any given training period. The model allows violation of sorties and flight time equity constraints and incurs penalties in the objective function when any of these constraints is violated. Specifically, H^f is the penalty per unit of violation of the upper bound on the number of sorties a pilot may fly in a training period. Conversely, L^f is the penalty per unit of violation of the lower bound. The upper and lower bounds on the sorties each pilot may fly during the training period are determined outside the model by calculating the mean number of sorties per pilot and allowing a deviation (specified by the decision maker) above and below this mean. Violation of the upper bound (S^u) on the number of sorties the squadron may fly for the training period is at a cost of U^{fu} per unit of violation, as the number of sorties for the training period is a fixed multiple of the squadron's quarterly fiscal allocation. There is also a penalty incurred when too few sorties are scheduled during the training period. U^{fl} is the penalty for each sortie not scheduled below S^u.

2. Constraints

The constraints are a mixture of standard and elastic constraints. The elastic constraints (1) and (7) include variables that are necessarily integer as they represent violations of limits on sorties scheduled. Although the decision variable s_{pe} and the elastic variables are integer, the measure of overall squadron readiness r_a is a continuous variable bounded between 0 and 1 and therefore this model is technically a mixed integer program.

The elasticity of the model allows certain constraints to be violated at a cost per unit violation. Post run analysis of violations may aid the decision maker in the distribution of quarterly funding and would provide strong support if a request additional funding to augment training becomes necessary.

Constraint (1) elastically limits the total number of sorties scheduled to the number allocated for the training period. Constraint (2), which contains the decision variable s_{pe} , is the sum of additional points earned, t_{pa}, by pilot p in mission area a. Constraint (3) then compares the additional points earned by pilot p in mission area a to the maximum number of additional points available (T^a_{pa}) for pilot p in mission area a. This comparison results in the generation of the variable q_{pa} , the fractional portion of the maximum additional points earned by pilot p in mission area a and reflects the individual readiness of each pilot. Constraint (4) is the average of all pilots' readiness levels in the squadron.

Constraint (5) is the scheduling restriction derived from the section and division requirements that are included in certain training events. The subset $E' \in E$

is that set of events that requires either a section or division to complete the event and this constraint requires that the number of pilots assigned to such events be multiples of two (for a section) or four (for a division). Constraint (6) requires that the model schedule at least the minimum number of pilots (G_e) to complete a training event.

Constraints (7) and (8) indicate that if pilot p is scheduled for event e, then the event must be scheduled.

Constraint (9) is the flight time equity constraints for the model, and bound the maximum and minimum number of sorties that a pilot may fly during the training period. Elasticized, the bounds may be violated at a specific penalty per unit of violation. By altering penalties or bounds the decision maker may relax these constraints and forego equity to achieve higher readiness, or tighten the requirement for flight time equity thereby forsaking additional readiness.

Constraint (10) bounds the readiness of the squadron in each mission area from above and below. Constraint (11) is an analogous bound for individual pilots. The lower bounds may be altered by the user to balance out the squadron readiness with pilot readiness, but constraints (10) and (11) are not elasticized and setting these bounds too tightly may result in infeasibility in the model. Constraint (12) provides the limit on the slack variable f_p , bounding it between 0 and the difference between the upper and lower bounds on the number of sorties per pilot.

Originally the model was formulated with the target point total in constraint (3) being total training points for pilot p in mission area a. The current formulation sets the requirement in terms of *additional points* pilot p must earn in mission area a to be considered combat-ready. This results in a smaller feasible region, the formulation becomes stronger, and is easier to solve.

IV. COMPUTATIONAL TRIALS

The scheduling model is implemented in GAMS [Ref. 2] , solved with XA v.8.0 [Ref. 3] on a PC using an 80486/33MHz processor, and tested using training and readiness data from two operational squadrons. This chapter presents a description of the data used to test the program and the computational results from variations in the data simulating potential scheduling scenarios.

A. DATA

Authentic squadron training and readiness data was obtained from two F/A-18 squadrons stationed at Naval Air Station Lemoore, California. Currently, the F/A-18 Community has the most extensive training matrix in Naval Aviation, encompassing 7 mission areas with 68 events. Squadron Onc data has 16 pilots, 68 events, and 7 mission areas. Squadron Two data has 17 pilots, 68 events, and 7 mission areas.

The data for each squadron is input to the model as two distinct sets. A permanent data set was derived from the CNAP/CNAL INSTRUCTION 3500.67B/63B training matrix. This data set includes readiness points earned in each mission area upon completion of an event, duration of an event qualification, and the number of aircraft required for each event. A scenario-specific data set is formed for each squadron which includes pilots and events completed, readiness points in each mission area and event expiration dates for each pilot, preference weights assigned to each mission area, deviations allowed from the mean number of flights per pilot, and penalties for each unit violation of the elastic constraints. Additionally, a "relative termination tolerance", OPTCR is also varied during testing of the model which specifies how close to optimality the solution is proven to lie. OPTCR is specified by the user as a value on [0,1] with 0 meaning 100% optimality and 1 meaning the first integer solution found causes termination.

B. TESTING

Test runs of the model were conducted to determine if the model generated output that was logical, and determine the effects of altering the various input data. Squadron readiness levels (and expiration dates) remained constant during each iteration. TABLE 1 presents the initial readiness levels of each squadron in each mission area (input to the model) and the final readiness levels (output) if no events are to be scheduled. If no events are scheduled, some mission areas are affected more than others either due to expiration dates passing or because qualification in some events is short lived. The data altered are: OPTCR, $\mathbf{S}^{ub}$ (maximum sorties per month), $\mathbf{H}^{f}$ and $\mathbf{L}^{f}$ (penalties for violating the upper and lower bounds on pilot flights), $\mathbf{U}^{fu}$ and $\mathbf{U}^{fl}$ (penalties for scheduling sorties beyond and below S^{ub}), deviation from the mean number of sorties per pilot, and mission area weights. Preliminary tests with OPTCR values below .03 induces excessive solution times with a very low "payoff" in increased readiness levels. Therefore model tests are reported with a constant OPTCR of .03 while other inputs are varied.

In terms of model output, time to solve, the number of sorties scheduled beyond what is available, and projected average squadron readiness levels in each mission area at the end of the scheduling period are the most significant data and are reported.. The actual value of the objective function is unimportant and is not listed.

TABLE 1. SQUADRON READINESS LEVELS

	SQUADRON 1 READINESS		SQUADRON 2 READINESS	
MISSION AREAS	INITIAL AVG POINTS	FINAL AVERAGE POINTS NO EVENTS SCHEDULED	INITIAL AVG POINTS	FINAL AVERAGE POINTS NO EVENTS SCHEDULED
AAW	34.41	17.41	37.90	33.24
ASU	43.71	37.06	42.20	36.82
STW	43.18	37.41	39.70	30.41
AMW	44.13	37.94	41.40	35.94
MIW	37.05	36.71	74.60	52.53
MOB	79.24	71.41	84.30	80.00
CCC	36.18	33.82	58.80	55.59

C. REASONABLENESS OF SCHEDULES PRODUCED

Before structured testing of the model, two baseline runs were conducted, for each squadron, to appraise the output of the model for reasonableness and to provide a basis of comparison for subsequent runs. The first run, a zero-sortie baseline, shows the effects of scheduling no flights. The data listed in TABLE 1 clearly indicate the intuitive expectation that readiness levels decrease significantly in all mission areas when no flights are scheduled. Because each of the training events offers readiness points in at least three mission areas, the probability of readiness in any one mission area not decreasing is minimal. The second runs are 200-sortie baselines described along with the output in TABLE 2. The number of sorties input to the model, 200, is based upon discussions with schedulers at the two squadrons,

TABLE 2. INITIAL MODEL TESTS

		SQUADRON 1		SQUADRON 2	
TIME (MIN:SEC)		3:51		4:02	
S^{UB} (SORTIES AVAILABLE)		200		200	
H^F/L^F (PILOT EQUITY PENALTIES)		5/5		5/5	
U^{FU}/U^{FL} (SORTIES PENALTIES)		2/2		2/2	
FLIGHT TIME EQUITY DEVIATION		50%		50%	
MISSION AREA	MISSION WEIGHT	OUTPUT READINESS (AVG POINTS)			
		INITIAL	FINAL	INITIAL	FINAL
AAW	500	37.90	40.50	34.41	22.82
ASU	500	42.20	70.81	43.71	65.29
STW	500	39.70	59.87	43.18	59.59
AMW	500	41.40	71.19	44.13	67.00
MIW	500	74.60	64.25	37.05	70.82
MOB	500	84.30	95.62	79.24	82.59
CCC	500	58.80	79.69	36.18	64.12
EXCESS SORTIES SCHEDULED		0		0	

and represents a somewhat greater than average number of sorties per month for an F/A-18 squadron, which yields easy-to-solve models. The penalties and flight time equity deviation were set arbitrarily. The readiness level increases over the zero-sortie baseline in all cases except for AAW in Squadron Two. Output of the model was manually verified for both squadrons and demonstrates sensible proposed pilot-to-training event assignment. APPENDIX C, TABLES C-1 to C-10 contain the detailed results for these model tests conducted. A sample of the model output is presented in APPENDIX D.

D. SUMMARY OF RESULTS

The baseline results indicate that the model will produce a face valid solution to the scheduling problem. However, the data should be varied to determine whether or not solutions are consistent and change reasonably with changes to input. The following sections summarize test results with varied input parameters.

1. Altering Penalties

Reducing flight time equity and sortie limit penalties increases the readiness in all mission area, as this results in additional sorties scheduled. Conversely, if the penalty values are too low, the model grossly violates the bound on sorties, and the output of the model becomes unusable. TABLES C-1, C-2, and C-6 contain the results obtained when these penalties are varied. Operational experience indicates that the number of excess pilot-to-event assignments made should be in the neighborhood of 0 to 15 depending upon the planning goals of the squadron commanding officer. In practice, some experimentation with the penalty values would be necessary to achieve the desired results.

2. Interaction of Penalties and Training Matrix Data

AAW points per event vary over a large number of events and qualifications last from one to three months. Consequently, many AAW events must be scheduled just to maintain a constant level of readiness. This was verified by the solutions presented by the model. If the flight time equity and/or sortie limit penalties are low, the sortie limit is grossly violated and the AAW readiness remains reasonable. If penalties are high and sortie limits reasonable, readiness levels in AAW either increased only slightly, as in Squadron One, or in the case of Squadron Two, decreased. These results are apparent in almost all of the tests but particularly apparent in tests documented in TABLES C-2, and C-4. This is verified in TABLES C-1, C-2, and C-8 which have higher sortie limits as well.

3. Reducing Flight Time Equity Deviation

The reduction of the flight time equity deviation increases solution time of the model and also decreases the readiness of the squadron. By restricting the model from favoring one pilot over another with more sorties, the model is forced to choose a less attractive, with respect to readiness, set of pilot-to-event assignments. In TABLES C-3 and C-7, when deviation is reduced, this outcome is not evident as the penalties for violating sortie equity and sortie availability are low and the model schedules additional events. However, as seen in TABLE C-8, when the penalties are increased, lowering deviation results in decreased readiness and increased solution times. Additionally, when flight time equity deviations are kept at reasonable levels (20% or less), and penalties increased to prevent excess sortie scheduling, solution times of the model increase. This is evident in TABLES C-5 and C-8 as solution times increased to just over 10 minutes.

4. Influence of Mission Area Weights

Altering mission area weights serves to shift the emphasis of the solution toward the more heavily weighted mission areas. However, larger increases in readiness may be seen in those mission areas where the weight is constant or is reduced. An example of this is seen in TABLE C-5. When ASU and STW mission weights are increased from 500 to 800, while AMW is decreased from 500 to 400, the largest increase in readiness is seen in AMW. This is due to the fact that there are some training events that have significant readiness points in more than one mission area. Thus, increasing a weight in one or more mission areas results in sorties being assigned to increase readiness in those areas but those sorties add significantly to the readiness in other areas as well. In the example of C-5, readiness in ASU and STW does increase as expected, but so does the readiness in AMW. This example shows that results are reasonable but changing mission area weights may produce unexpected outcomes.

V. CONCLUSIONS AND RECOMMENDATIONS

This prototype flight scheduling model demonstrates the potential of using a computerized method of assigning pilots to training events to improve the combat readiness of a squadron. The model provides solutions which are generally within 3% of optimality in five minutes on a PC. Additionally the model requires a modest amount of data and automatically calculates projected readiness levels for both the squadron and pilots.

The model was tested using data from the F/A-18 community which has the most extensive training matrix in the Navy. As a scheduling aid, the model has the potential to save schedulers valuable time when trying to produce monthly training schedules and calculating expected readiness levels or when rescheduling training sorties due to unexpected or unmodelable exigencies.

Since solution times are short, the model could be used by an operations officer to study the tradeoff between flight time equity among pilots and readiness. Furthermore, the model could also be used to explore the incremental effects on readiness of exceeding sortie limits.

The model would be improved by introducing a database interface to simplify data entry and review of solutions. It should be possible to modify the model to determine minimum sortie requirements to maintain or achieve given readiness levels to aid in budgeting and in the revision of current training doctrine. Further research is necessary to generate potential crew-to-event assignments for multicrew aircraft including the Rotary-Wing, E-2C, and the Maritime Patrol communities.

APPENDIX A: GLOSSARY OF TERMS

PMAs

AAW	Anti-Air Warfare
ASW	Anti-Submarine Warfare
STW	Strike Warfare
ASU	Anti-Surface Warfare
CCC	Command Control and Communications
MOB	Mobility
INT	Intelligence
ELW	Electronic Warfare
MIW	Mine Warfare
AMW	Amphibious Warfare
LOG	Logistics
FSO	Fleet Support Operations
NSW	Naval Special Warfare

Communities

Aircraft Carrier Deployed:

F-14	Current U.S. Navy air superiority combat fighter aircraft.
F-18	Multi-mission fighter and attack aircraft.
A-6	Medium attack aircraft (soon to be phased out of fleet inventory).
E-2C	Airborne command and control platform for naval aircraft.
C-2	Long range ship to shore delivery aircraft.
EA-6	Electronic Warfare aircraft.
S-3	Long range Anti-Submarine aircraft.
SH-3	Anti-Submarine helicopter (to be replaced by the SH-60F)

Detachment Deployed:

SH-2	Anti-Submarine helicopter deployed on small surface combatants (soon to be phased out of fleet inventory).
SH-60B	Anti-Submarine helicopter deployed on small surface combatants.
P-3	Long Range Maritime Patrol aircraft (also deploys as a squadron).
CH-53E	Heavy lift capable cargo helicopter.
MH-53E	Mine Warfare helicopter.
CH-46D	Medium lift capable cargo helicopter.
VH-3	VIP passenger helicopter.

APPENDIX B: COMMUNITIES AND PMAs

TABLE B1. PMA COVERAGE BY COMMUNITY

	AAW	ASU	STW	CCC	MOB	INT	ELW	MIW	AM	FSO	LOG	NSW	ASW
F-14	✓	✓		✓									
F-18	✓	✓	✓	✓	✓			✓	✓				
A-6		✓	✓	✓	✓			✓	✓				
E-2C	✓	✓	✓	✓	✓	✓	✓						
C-2				✓	✓					✓	✓	✓	
EA-6	✓	✓	✓	✓	✓	✓	✓						
S-3		✓		✓	✓	✓	✓	✓					✓
SH-3				✓	✓					✓			✓
SH-2		✓		✓	✓		✓						✓
SH-60B		✓		✓	✓		✓						✓
P-3		✓		✓	✓	✓	✓	✓			✓		✓
CH-				✓	✓					✓	✓		
MH-				✓	✓			✓					
CH-				✓	✓					✓	✓		
VH-3				✓	✓					✓	✓		

APPENDIX C: DATA SET COMPARISONS

TABLE C-1. ALTERING PENALTIES H^f, L^f, U^{fu}, and U^{fl}

Squadron One: Comparison 1				
Time (min:sec)		1:00	2:36	2:23
S^{ub}		200	200	200
H^f/L^f		4/5	3/1	3/1
U^{fu}/U^{fl}		2/2	2/1	1/1
Flight Time Equity Deviation		50%	50%	50%
Mission Area	Mission Weight	Final Readiness Level (Avg. Points)		
AAW	500	46.94	53.75	53.75
ASU	500	71.06	72.31	72.31
STW	500	60.12	63.25	63.25
AMW	500	72.69	75.44	75.44
MIW	500	64.25	64.25	64.25
MOB	500	95.62	95.62	95.62
CCC	500	95.62	95.62	81.56
Excess Sorties Scheduled		0	0	0

TABLE C-2. ALTERING SORTIES ALLOCATED, S^{ub}

Squadron One: Comparison 2				
Time (min:sec)		2:12	1:59	1:55
S^{UB}		175	150	125
H^F/L^F		3/3	3/3	3/3
U^{FU}/U^{FL}		1/2	1/2	1/2
Flight Time Equity Deviation		50%	50%	50%
Mission Area	**Mission Weight**	**Final Readiness Level (Avg. Points)**		
AAW	500	49.06	46.94	46.94
ASU	500	72.06	71.87	71.50
STW	500	63.00	61.81	61.44
AMW	500	74.81	74.44	74.44
MIW	500	64.25	64.25	64.25
MOB	500	95.62	95.62	95.62
CCC	500	81.56	81.56	81.56
Excess Sorties Scheduled		1	13	37

TABLE C-3. ALTERING FLIGHT TIME EQUITY DEVIATION

SQUADRON ONE: COMPARISON 3				
TIME (MIN:SEC)		2:07	3:40	3:55
S^{UB}		150	150	150
H'/L'		3/3	3/3	3/3
U^{FU}/U^{FL}		1/2	1/2	1/2
FLIGHT TIME EQUITY DEVIATION		40%	30%	20%
MISSION AREA	MISSION WEIGHT	FINAL READINESS LEVEL (AVG. POINTS)		
AAW	500	46.94	46.94	47.12
ASU	500	71.50	71.50	71.56
STW	500	61.44	61.44	61.37
AMW	500	74.44	74.44	74.45
MIW	500	64.25	64.25	64.25
MOB	500	95.62	95.62	95.62
CCC	500	81.56	81.56	81.56
EXCESS SORTIES SCHEDULED		12	12	14

TABLE C-4. REDUCING CANDIDATE EVENTS

SQUADRON ONE: COMPARISON 4				
TIME (MIN:SEC)		12:07	3:45	4:09
S^{UB}		150	150	150
H^{F}/L^{F}		2/2	2/2	2.5/2
U^{FU}/U^{FL}		2/1	2.5/1	2.5/2
NUMBER OF CANDIDATE EVENTS		50	58	58
FLIGHT TIME EQUITY DEVIATION		40%	40%	40%
MISSION AREA	MISSION WEIGHT	FINAL READINESS LEVEL (AVG. POINTS)		
AAW	500	48.06	44.62	41.62
ASU	500	72.31	72.50	72.56
STW	500	65.75	66.06	64.87
AMW	500	68.50	68.44	68.25
MIW	500	64.25	64.25	64.25
MOB	500	98.44	98.44	96.56
CCC	500	79.06	78.44	76.25
EXCESS SORTIES SCHEDULED		37	24	6

TABLE C-5. ALTERING MISSION AREA WEIGHTS

SQUADRON ONE: COMPARISON 5				
TIME (MIN:SEC)	2:54	2:46	3:31	2:57
S^{UB}	175	150	170	160
H^F/L^F	2/2	2/2	2/2	2/2
U^{FU}/U^{FL}	2/2	2/2	2/2	2/2
FLIGHT TIME EQUITY DEVIATION	20%	20%	20%	20%
MISSION AREA	FINAL READINESS LEVEL [MISSION WEIGHT]			
AAW	45.56 [400]	43.25 [400]	44.12 [400]	43.81[400]
ASU	73.75 [800]	73.75 [800]	73.75 [750]	73.75[750]
STW	66.44 [800]	66.19 [800]	66.19 [750]	66.19[750]
AMW	73.87 [400]	73.31 [400]	73.31 [400]	73.31[400]
MIW	64.25 [300]	64.25 [300]	64.25 [300]	64.25[300]
MOB	96.56[200]	96.56 [200]	96.56 [200]	96.56[200]
CCC	81.56[200]	81.56[200]	82.19[200]	82.19[200]
EXCESS SORTIES SCHEDULED	0	17	0	9

TABLE C-6. ALTERING PENALTIES H^f, L^f, U^{fu}, and U^{fl}

Squadron Two: Comparison 1					
Time (min:sec)		3:01	1:56	2:26	2:29
S^{ub}		150	150	150	175
H^f/L^f		4/4	3/3	3/3	3/3
U^{fu}/U^{fl}		2/2	2/2	3/2	2.5/2
Flight Time Equity Deviation		50%	50%	50%	50%
Mission Area	Mission Weight	Final Readiness Level (Avg. Points)			
AAW	500	19.65	20.12	20.00	20.12
ASU	500	62.35	64.12	62.41	63.59
STW	500	55.18	57.06	55.14	55.88
AMW	500	64.00	67.35	63.94	66.35
MIW	500	68.18	68.76	68.18	68.76
MOB	500	78.18	78.18	78.18	78.18
CCC	500	62.06	64.71	62.65	63.53
Excess Sorties Scheduled		3	22	6	14

TABLE C-7. ALTERING FLIGHT TIME EQUITY DEVIATION

SQUADRON TWO: COMPARISON 2					
TIME (MIN:SEC)		3:06	3:14	3:15	4:08
S^{UB}		150	150	150	150
H^{T}/L^{T}		3/3	3/3	3/3	3/3
U^{FU}/U^{FL}		3/2	3/2	3/2	3/2
FLIGHT TIME EQUITY DEVIATION		40%	30%	20%	10%
MISSION AREA	MISSION WEIGHT	FINAL READINESS LEVEL (AVG. POINTS)			
AAW	500	19.76	20.24	20.24	20.24
ASU	500	62.35	62.35	62.35	63.06
STW	500	54.82	55.82	55.82	55.76
AMW	500	63.71	63.76	63.76	64.06
MIW	500	69.82	69.82	69.82	69.82
MOB	500	80.41	80.41	80.41	79.94
CCC	500	62.65	62.65	62.65	61.47
EXCESS SORTIES SCHEDULED		8	12	12	12

TABLE C-8. REDUCING FLIGHT TIME EQUITY DEVIATION (HIGH PENALTIES)

SQUADRON ONE: COMPARISON 6					
TIME (MIN:SEC)		3:06	3:42	4:03	10:57
S^{UB}		175	175	175	175
H^{F}/L^{F}		4/4	4/4	4/4	4/4
U^{FU}/U^{FL}		3/3	3/3	3/3	3/3
FLIGHT TIME EQUITY DEVIATION		40%	30%	20%	10%
MISSION AREA	MISSION WEIGHT	FINAL READINESS LEVEL (AVG. POINTS)			
AAW	400	42.41	42.65	42.59	42.08
ASU	800	71.24	71.06	71.00	70.65
STW	800	61.06	61.00	61.12	60.76
AMW	400	72.76	72.18	72.18	72.18
MIW	300	64.12	64.12	64.12	64.12
MOB	200	90.59	90.59	90.59	90.59
CCC	200	82.88	83.24	82.25	82.25
EXCESS SORTIES SCHEDULED		0	0	0	0

TABLE C-9 REDUCTION IN THE NUMBER OF CANDIDATE EVENTS

SQUADRON TWO: COMPARISON 4					
TIME (MIN:SEC)		2:39	2:13	1:46	0:37
S^{UB}		175	175	175	175
U^{+}		14	11	10	0
H'/L'		3/3	3/3	3/3	3/3
U^{FU}/U^{FL}		2/2	2/2	2/2	2/2
NUMBER OF CANDIDATE EVENTS		58	53	48	38
FLIGHT TIME EQUITY DEVIATION		10%	10%	10%	10%
MISSION AREA	MISSION WEIGHT	FINAL READINESS LEVEL (AVG POINTS)			
AAW	400	20.59	20.71	20.71	19.29
ASU	800	68.18	65.41	65.18	65.53
STW	800	62.24	60.47	59.76	50.71
AMW	400	69.18	67.88	67.65	64.12
MIW	300	70.18	72.18	70.88	72.18
MOB	200	80.24	79.94	79.53	82.59
CCC	200	57.06	55.29	56.47	57.06
EXCESS SORTIES SCHEDULED		14	11	10	0

APPENDIX D: SAMPLE MODEL OUTPUT

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MONTHLY SQUADRON SORTIE SCHEDULING PROBLEM

----    547 VARIABLE  UTOP.L                  =  12.00
----    548 VARIABLE  UBOT.L                  =   0.00

----    552 PARAMETER SQDRAVG         squadron average point totals
                                      in mission area
AAW 20.24
ASU 63.06
STW 55.76
AMW 64.06
MIW 71.12
MOB 79.94
CCC 61.47

----    554 VARIABLE  S.L             1 IF PILOT p SCHEDULED FOR
EVENT e T9    T10     T16    T17     T18   T19
P1                     1                    1
P2                                     1
P3                            1
P4                     1      1
P5                     1      1
P6      1                     1
P7      1                              1
P9                            1
P1                            1
P1             1              1
P1                            1
P1                            1
P1                            1         1

  +    T20    T21    T28     T29      T31    T32

P1             1      1       1         1
P2      1
P3                    1       1
P4      1             1
P5      1
P6                    1
P10                                      1
P11                   1
P12     1             1        1
P13     1
P14                            1
P15     1                                      1
P16                    1       1

        554 VARIABLE  S.L             1 IF PILOT p SCHEDULED FOR
EVENT e

  +  T34     T35    T37     T38    T40    T41
```

P1	1		1			
P2	1	1	1	1		1
P3	1		1	1		1
P4	1	1	1		1	
P5	1	1	1		1	1
P6			1		1	
P8	1					1
P9	1	1	1		1	1
P10	1		1	1	1	
P11	1	1	1		1	1
P12					1	1
P13	1		1		1	1
P14	1	1	1		1	1
P15	1		1		1	1
P16		1	1	1		
P17						1

+	T43	T44	T45	T46	T52	T56
P1		1				
P2		1		1		
P3		1				
P4		1				
P5		1		1	1	
P7				1		
P8	1			1		
P9		1		1		
P10			1	1		
P11	1	1				1
P13	1	1				
P14		1		1		
P15		1				
P16	1	1				
P17	1					

+	T57	T59	T61	T62	T65
P1				1	
P2				1	
P3				1	
P4		1		1	
P5					1
P6				1	1
P7			1		
P8	1			1	
P9				1	
P10					1
P11		1		1	
P12		1		1	
P13				1	
P14		1		1	1
P15				1	
P16				1	
P17	1				1

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